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# INSTRUCTIONS

## For the USE of

## HADLEY'S Quadrant,

CONTAINING,

The Principles on which that admirable Inſtrument is conſtructed,

With a

Deſcription and Uſe of the Nonius Diviſions.

As Made and Sold by

**GEORGE ADAMS,**

MATHEMATICAL INSTRUMENT-MAKER to
his Royal Highneſs *George* Prince of *Wales*.

At *Tycho Brahe*'s Head in *Fleet-Street*, between *Serjeant's-Inn* and *Water-Lane*.

Where Gentlemen may be ſupplied with all Sorts of Mathematical Inſtruments for Land or Sea; Telleſcopes of all Sizes for Day or Night; together with all other Optical and Philoſophical Inſtruments of the neweſt Invention.

[1789 ?]

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10. 8. 10.

THE Inſtrument is an octant, and therefore its Arch contains only 45 degrees. Yet from the nature of reflection made on the two mirrors; each half degree, on the arch anſwers the purpoſe of a whole degree, wherefore it is divided into 90 degrees.

Some of theſe Inſtruments are ſubdivided into every two Minutes by means of a Diagonal, the Uſe of which is ſo well underſtood, as to require no explanation here.

But as many of them are ſubdivided by means of a Nonius Diviſion to every ſingle Mimute, on the fiducial Arch of the Index. I ſhall (after explaining the Theory of the Inſtrument) give a particular Explanation thereof.

The Conſtruction of this Inſtrument depends upon the following Principle.

If a Mirror is moveable about a Center, that is, if it changes its Inclination or Situation; the angular Motion of the Images are double to that of the Mirror.

### *Demonſtration.*

Let AB Fig. 1. Repreſent the firſt Situation of the central Mirror. OE an incident Ray, EF, a reflected ray, and let the Mirror be ſuppoſed to turn upon an Axis which paſſes thro' the Point E, until it comes into the Situation CD, in this laſt Situation of the Mirror, the incident Ray OE will have EG for its reflected Ray. I ſay that the Angle FEG, which expreſſes the angular Motion, or the Space that the reflected Ray is removed from its firſt Situation E F, is double to the angular Motion of the Mirror.

For the Motion of the Mirror A B, being towards the reflected Ray E F, if you give it the Direction C D, it is clear that the Perpendicular Line H E, alſo approaches towards the incident Ray O E, with an angular Motion equal to that of the Mirror. Becauſe it is ſuppoſed to remain always perpendicular to the Mirror, and then it will have the Direction K E.

If therefore the angular Motion of the Mirror makes it receed from the incident Ray to a certain Diſtance, it advances as much towards the perpendicular; but the perpendicular muſt be in the middle between the two rays.

Conſequently the reflected ray approaches towards it in an angle equal, to that by which the other receeds from it.

Hence we ſee two equal Quantities of the angular Motion of the Mirror, whereby the reflected Ray approaches the incident Ray which is immoveable. That of the Motion of the perpendicular, and that of its own proper Motion, conſequently the reflected Ray advances towards the incident Ray, in a Quantity double to that of the angular Motion of the Mirror.

If, for Example, the incident Ray O E ſhould make an Angle of 30 Deg. with the Mirror A B, the reflected Ray E F would make with the ſame Mirror an Angle of 30. Deg. alſo, becauſe the Angles of Reflection are equal to the Angles of Incidence.

Now let the Mirror A B deſcribe an Angle of 10 Deg. about an Axis which ſhall paſs through the Point E, and let the Direction C D be given to it; it is clear, that the incident ray O E will then make an angle of 40 deg. with the mirror. The perpendicular H E was 60 deg. from the incident ray O E, in the former ſituation A B of the mirror; but in this new ſituation it will be removed to K E, and be no more than 50 deg. becauſe its angular motion is equal to that of the mirror. It would then be 70 deg. from the former reflected ray E F, if that alſo did not change its place: but the perpendicular muſt always be in the middle between the two rays of incidence and reflection;

tion; whence in the new direction C D of the mirror, the reflected ray is obliged to deſcribe an arc of 20 deg. whilſt the mirror deſcribes but 10 deg. wherefore the angle which expreſſes the reflected motion, is always double to that which expreſſes the motion of the mirror. Hence, if the mirror deſcribes an Octant, the reflected ray will deſcribe a Quadrant.

It is very eaſy to apply this principle to our inſtrument: for the image of the ſun paints itſelf upon the mirror D. fig. 2. from thence it is reflected upon one of the little horizon glaſſes G or H: the ſun can only change its altitude to preſerve the incidence of the reflected ray upon the ſame point of one of the ſmall glaſſes. We need only move the mirror D by means of the index E, which expreſſes the angular motion of the reflected ray, and we ſhall have a mirror D which turns upon the center of the inſtrument, and a reflected ray, the motion of which is always double to the angular motion of the mirror. Wherefore 45 deg. on the limb of the octant, which expreſſes the motion of the mirror D, are equal in real value to 90 deg. of the reflected ray, and are marked out by the index as ſuch.

## *The deſcription and uſe of the Nonius diviſion.*

For the right underſtanding the reaſon of theſe ſubdiviſions, it will be neceſſary to premiſe, that if a right Line A B, *Fig.* 1, be divided into any number of equal parts, A c, c d, d e, e B, and an equal Line, F G, be divided into other equal parts, one more in number than the parts of the Line A B.

I ſay that F h, h i, i k, k l, l G, will fall ſhort of Ac, Ad, Ae, A B, reſpectively by 1, 2, 3, 4 parts of A c, for let the Lines A B and F G be coincident at both Ends, then (by the 15th of the V. of *Euclid*) as any multiples of two quantities A c, and F h, have the ſame Proportion as the quantities themſelves, it will be as, A c : F h : : A d : F i : : A e : F k : : A B : or F G : F l. and diſjointly as A c : c h : : Ad : di : : Ae : ek : : AB or FG : Bl or Gl : the conſequents c h, d i, e k, B l, are therefore in the ſame arithmetical progreſſion, as the antecedents A c, A d, A e, A B, and the firſt of the conſequents c h, is the ſame part of its antecedent A c, as the laſt conſequent B l is of the laſt antecedent A B; or as F h is of FG, the number of parts in A B and F l, being equal by the firſt ſuppoſition. It is alſo manifeſt that any two coincident arches of a circle will have the ſame property.

I have ſubſtituted a part of the quadrantal arch in *Fig.* 4. which, together with as much of the index as contains the Nonius is drawn of its real ſize, that the reader might the more readily underſtand the nature of theſe admirable ſubdiviſions.

The Nonius VV, *fig.* 4. which is near the end of the index, moves againſt the diviſions of the Arch, whoſe degrees are divided into 3 equal parts, containing 20 minutes each; therefore, to ſubdivide thoſe diviſions in ſingle minutes, it is neceſſary, that nineteen of theſe, or 6 deg. 20 min. be taken for the length of the Nonius VV, *fig.* 4. and that this length VV, be divided into 20 equal parts, then will each diviſion in the line VV be ſmaller than the third part of a degree, or 20 minutes, by the twentieth part of 20 minutes, that is one minute.

The middle line of this Nonius VV, *fig.* 4. ſtands at 51 deg. 20 min. and ſomewhat more; therefore, in order to determine how many minutes more, paſs your eye along them from the middle line towards the right hand, and you will find that the eighth diviſion of the Nonius exactly correſponds with the eighth ſubdiviſion of the degrees, from 51 deg. 20 min. which ſhews that the Angle of the index or altitude of the ſun, is 8 minutes more than 51 deg. 20 min. which is 51 deg. 28 min.

When it happens that no one ſtroke upon the arch is directly oppoſite to a ſtroke upon the Nonius; then look for that ſingle part upon the limb which is ſo oppoſed to a ſingle part upon the Nonius, as to exceed it at both ends equally; then you may allow 30 ſeconds more.

This way of ſubdividing by a Nonius, is preferable to the common method by diagonals; becauſe they cannot be drawn ſo exactly as the lines upon the Nonius, and alſo becauſe their interſections with the index or fiducial edge, cannot, by reaſon of their great obliquity to each other, be determined ſo exactly by the eye, as the coincidence of two ſtrokes in the Nonius and arch, which ſtand directly oppoſite to one another.

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# INSTRUCTIONS

For the Use of

# Hadley's Quadrant.*

Made and Sold by

## *GEORGE ADAMS*,

Instrument-Maker to his Majeſty's
Office of Ordnance,

At *Tycho Brahe*'s Head, the Corner of
*Racquet-Court*, in *Fleet-Street*, *London*.

THE Inſtrument is an Octant A B C, (ſee the Figure) having its Arch B C accurately divided into Ninety equal Parts or Degrees, which are again ſubdivided into 20 Min. The whole Degrees are diſtinguiſhed by Lines drawn through three concentric Circles; and the other Subdiviſions of 20 Min. each, are pointed out by Lines drawn

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* Extracted from a Deſcription of a new Inſtrument invented by *John Hadley*, Eſq;

through the two outward concentric Circles, and theſe laſt Subdiviſions are again ſubdivided into Minutes, ſometimes by a Diagonal, and ſometimes by a *Nonius*. Altho' this Inſtrument is but an Octant, and its Diviſions no more than half Degrees, yet from its Conſtruction and the Nature of Reflection, it anſwers to as many whole Degrees, whence it is in effect a Quadrant. A Label or Index E, is moveable about the Center, and marks the Diviſions graduated on the Arch, over the Center of the Inſtrument. But on that of the Index is fixed a Glaſs Mirrour D at right Angles to the Plane thereof. This Glaſs alters its Direction as the Index ſlides along the Arch, and reflects the Image of the Sun or Star to either of the Horizon Glaſſes; that is, to the South Horizon Glaſs G, for the fore Obſervation, and to the North Horizon Glaſs H, for the backward Obſervation.

The Glaſs G hath that Part quickſilvered which is next the Plane of the Octant, the upper Part being left tranſparent on purpoſe, to ſee the Horizon through it. This Glaſs returns a ſecond Image of the Sun or Star to the Eye, placed at the South Vane L, in forward Obſervations.

The Glaſs H receives the ſecond Image from the Index Glaſs D, and reflects it to the Eye placed at the North Vane M, in backward Obſervations. This Glaſs has a narrow tranſparent opening, thro' which the Horizon is to be viewed.

Each of theſe Glaſſes G and H, have a circular Motion parallel to the Plane of the Inſtrument, by means of two Leavers placed on the backſide of the Quadrant; and by means of two Screws which paſs through the Foot of each Glaſs, may be ſet perpendicular to the ſame Plane, if they ſhould by any Accident, &c. be altered from that Poſition.

There are two red Glaſſes at K, fixed in Braſs Frames, being one of a lighter, the other of a darker Colour. Their Uſe is to prevent the Sun's bright Rays from offending the Obſerver's Eye; theſe move on one Center, and may be uſed either ſeparate or together, according to the Brightneſs or Faintneſs of the Sun.

Theſe coloured Glaſſes, when uſed in the fore Obſervation, are to be put into a Hole at F, and when for the backward Obſervation into a Hole at N.

The South Vane L, for the fore Obſervation hath two Holes to direct the Sight, one at the Height of the Quickſilver'd Edge, the other about the Middle of the tranſparent Part of the South Horizon Glaſs G.

The North Vane M, for the back Obſervation, hath but one Hole placed at the Middle of the tranſparent Part of the Glaſs H.

There is great Curioſity in the Glaſſes; for they ought to be moſt perfectly flat, and of an equal Thickneſs, that thereby both their Surfaces may be perfectly parallel to each other, in order to have but one reflected Image, which is the Reaſon that common looking Glaſs will not do. The dark Glaſſes ought alſo to be very true.

The Purchaſer may eaſily know whether the Glaſſes be good by taking Notice of any bright Object; as the Sun, whether the Edges of it appear perfectly ſharp, and diſtinct, and in one, which can never be unleſs the Planes of the Glaſſes are truely parallel, and they are beſt tried when the Index is near 90 Degrees, which will ſhew the Error moſt.

### *To adjuſt the Glaſſes.*

For the fore Obſervation, ſet the Index to the Beginning of Degrees --- by bringing it cloſe to the Button P, which will ſtop it at that very Point, and holding the Inſtrument upright, look through the lower Hole in the South Vane L, and through the tranſparent Part of the South Horizon Glaſs G, and obſerve whether the Edge of the Sea ſeen in the quickſilver'd Part, joins in the ſame ſtreight Line with the ſame Edge ſeen through the unquickſilver'd Part; if not, bring them into one Line by the Help of the Leaver under the Glaſs G on the Back of the Inſtrument.

For the back Obſervation, bring the Edge of the Sea ſeen by Reflection, to coincide with the Edge of the Sea ſeen through the tranſparent Slit of the Glaſs H, by Help of the Leaver on the Back-ſide of the Inſtrument: The Index being firſt ſet as much beyond the Beginning of Degrees, as double the Angle of the Dip † of the viſible Horizon.---Becauſe if you are much above the Surface of the Sea, you are not in the ſame ſtreight Line with the two oppoſite Parts of the Horizon,

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† See the Table for the Angle of the Dip of the Sea above the viſible Horizon in Page 8.

Horizon. Example, ſuppoſe the Obſerver to be elevated above the Surface of the Water 12 Feet, the Dip of the viſible Horizon will be 4 Minutes forwards, and as much backwards; therefore the Index muſt be ſet off eight Minutes before the Beginning of Degrees.

⁂ The Edge of the Sea ſeen from behind by Reflection will be inverted, *i. e.* The Water will appear above, and Sky below. And if the two Edges of the Sea croſs each other, the Inſtrument is not held upright.

## *To obſerve the Altitude of the Sun or Stars.*

Hold the Octant as upright as may be, with the Arch downwards, your Face to the Sun, and placing the Eye to the South Vane L, for the forward Obſervation, direct your Sight through the tranſparent Part of the Glaſs G, to that Part of the Horizon which lies directly under the Sun. Then by moving the Index forward, bring the Image of the Sun to appear as tho' it really lay upon the Ege of the Sea. And the Degrees and Minutes pointed out by the Index is the Altitude ſought. In this Caſe the Image of the Sun appears in the ſame Poſition as when ſeen by the naked Eye, that is, it is not inverted.

If the Reflection be too bright for the Eye, turn up one or both of the coloured Glaſſes, as Occaſion requires.

When the Sun is made to appear upon the Horizon, if you lean the Inſtrument firſt to the right and then to the left Hand, it will ſeem to deſcribe an Arch, the loweſt Part of which muſt be ſet to the Horizon, and then the Inſtrument is perfectly upright.

For the Back Obſervation hold the Octant as before, as upright as poſſible, with your Back towards the Sun; and placing your Eye to the North Vane M, look through the tranſparent Part of the Glaſs at the Horizon, and at the ſame Time ſlide the Index till the Image of the Sun joins the Edge of the Sea.---

In order to know when the Inſtrument is held upright, keep it and your Arms ſteady and turn yourſelf ſideways, (as it were upon your Heel) to the right and left; and you will ſee the Image of the Sun glide along the Horizon, if the Inſtrument be in a Vertical Poſition, and if not, the Sun will deſcribe a Line which croſſes the Edge of the Sea.

To obſerve by a Star forwards, ſet the Index to the Beginning of Degrees, and look up directly at it, by which Means it will appear in its own Place as well by Reflection as it does to the naked Eye.---Then ſlide the Index, and the Star will deſcend till it touches the Horizon, by which Method you'll neither looſe Sight nor miſtake it for any other Star.---

When the Horizon is bright, and the Star faint, it will be more convenient to uſe the back Obſervation. Therefore look directly at the Star, and bring the Edge of the Sea to touch the Star by Reflection, and the Index will ſhew the Altitude thereof.

*To find the Latitude at Sea*, an Obſervation muſt be made, and frequently repeated, before the Sun comes to the Meridian, in order to obtain his greateſt Height, or Meridian Altitude; by which, and the Declination of the Sun, taken out of the Tables for that Purpoſe, the LATITUDE may be readily found, according to the common Rules delivered in every Treatiſe of Navigation.

That the Latitude of a Place taken by this Inſtrument, may be as correct as poſſible; it muſt be obſerved, that when the Eye of the Obſerver, is above the Surface of the Sea, the Plane paſſing through the Center of his Eye, parallel to the Horizon, will be above the real Horizon, ſo that the Altitude of the Sun taken by the Quadrant, will by that Means be as much greater than his real Altitude, as the Plane of that apparent Horizon is below that of the real one; and therefore, that Difference being eſtimated, muſt be taken from his obſerved Altitude, in order to find his real Altitude; and as the Height of the Obſerver's Eye, is more or leſs from the Surface of the Sea, I have inſerted a Table of Correction for that Purpoſe.

Since from the Principles of Optics, Rays of Light in paſſing from a Rarer into a Denſer Medium, are refracted towards the perpendicular; therefore the Rays that proceed from the Sun, muſt, by the interpoſing Atmoſphere, be refracted towards the Perpendicular, before they can reach the Surface of the Earth; conſequently, the obſerved Altitude will be greater than the Sun's real Altitude.

The Refraction being different in different Altitudes, I have inſerted Mr. FLAMSTEAD's Table thereof.

And as both theſe Errors are to be ſubſtracted from his apparent Altitude on the Quadrant; Therefore if the Minutes correſponding to the Height of the Eye, above the Surface of the Sea, be added to the Minutes and Seconds in the Table of Refractions, anſwering to his apparent Altitude; and their Sum ſubſtracted from the Altitude given by the Quadrant, the Remainder will be the Sun's true Altitude.

*N. B.* If the Zenith Diſtance be taken, both theſe Errors are to be added thereto.

A TABLE *ſhewing the Depreſſion, or Dip of the viſible Horizon, below the true Horizontal Plane*; according to ſeveral Heights (therein mention'd of the Obſerver's Eye above the Surface of the Sea; to be *ſubſtracted* from the Altitude found by the Inſtrument, and added to the Zenith-Diſtance.

| The Eye above the Surface of the Sea, *in Feet*. | Viſible Horizon depreſs'd *in Minutes*. |
|---|---|
| 1 | 1 |
| 3 | 2 |
| 7 | 3 |
| 12 | 4 |
| 18 | 5 |
| 27 | 6 |
| 40 | 7 |

Mr.

## *Mr.* FLAMSTEAD's *TABLE of Refraction, to be ſubſtracted from the* Altitude, *and added to the* Zenith-Diſtance, *found by the Inſtrument.*

| Deg. Appt. Alt. | Refract. | | Deg. Appt. Alt. | Refract. | | Deg. Appt. Alt. | Refract. | |
|---|---|---|---|---|---|---|---|---|
| ° | ′ | ″ | ° | ′ | ″ | ° | ′ | ″ |
| 0 | 33 | 00 | 18 | 2 | 29 | 41 | 0 | 56 |
| ½ | 26 | 38 | 19 | 2 | 21 | 42 | 0 | 54 |
| 1 | 23 | 22 | 20 | 2 | 14 | 43 | 0 | 52 |
| 1½ | 20 | 17 | 21 | 2 | 07 | 44 | 0 | 50 |
| 2 | 17 | 26 | 22 | 2 | 01 | 45 | 0 | 48 |
| 2½ | 15 | 15 | 23 | 1 | 55 | 46 | 0 | 46 |
| 3 | 13 | 23 | 24 | 1 | 50 | 47 | 0 | 45 |
| 3½ | 11 | 53 | 25 | 1 | 45 | 48 | 0 | 44 |
| 4 | 10 | 39 | 26 | 1 | 40 | 49 | 0 | 42 |
| 4½ | 9 | 38 | 27 | 1 | 36 | 50 | 0 | 40 |
| 5 | 8 | 48 | 28 | 1 | 31 | 51 | 0 | 39 |
| 6 | 7 | 26 | 29 | 1 | 27 | 52 | 0 | 38 |
| 7 | 6 | 25 | 30 | 1 | 23 | 53 | 0 | 37 |
| 8 | 5 | 37 | 31 | 1 | 20 | 54 | 0 | 36 |
| 9 | 5 | 02 | 32 | 1 | 17 | 55 | 0 | 34 |
| 10 | 4 | 33 | 33 | 1 | 14 | 60 | 0 | 29 |
| 11 | 4 | 06 | 34 | 1 | 11 | 65 | 0 | 24 |
| 12 | 3 | 45 | 35 | 1 | 09 | 70 | 0 | 19 |
| 13 | 3 | 29 | 36 | 1 | 07 | 75 | 0 | 14 |
| 14 | 3 | 13 | 37 | 1 | 05 | 80 | 0 | 09 |
| 15 | 3 | 00 | 38 | 1 | 02 | 85 | 0 | 04 |
| 16 | 2 | 48 | 39 | 1 | 00 | 90 | 0 | 00 |
| 17 | 2 | 38 | 40 | 0 | 58 | | | |

From what has been ſaid, it follows, that to obtain the Sun's true Altitude, we muſt ſubtract from his apparent Altitude both the Quantity of the *Horizontal Dip* and that of *Refraction*; and alſo, In order to render the Obſervation as Accurate as poſſible, it will be neceſſary to obſerve, that,

⁂ In the fore Obſervation, if the lower Part of the Sun's Limb touches the Horizon, add 16 Minutes; if the upper Limb, ſubtract 16 Minutes; either to or from the Degrees ſhewn by the Index.

In the Back Obſervation the Sun appears inverted, that is, the upper Limb of the Sun after Reflection appears undermoſt. So that in taking the Altitude by the back Obſervation, if the lower apparent Limb of the Sun be uſed, ſubtract 16 Minutes --- if the upper, add 16 Minutes to the Altitude ſhewn by the Index.

### BUT BE VERY CAREFUL,

That the Sun's Semidiameter be either added to, or ſubtracted from, the *Altitude* obſerved, which gives the true *Altitude*, and not to or from the *Zenith-Diſtance*, (as ſeveral by Miſtake have done) by which an Error of 32 Minutes may be committed.

EXAMPLE,

## EXAMPLE.

| | deg. | m. |
|---|---|---|
| Suppoſe the Altitude obſerved be | 59 | 15 |
| Sun's Semidiameter, when obſerved by the lower Edge, being added | 00 | 16 |
| Gives the true Altitude | 59 | 31 |
| Which when taken from | 90 | 00 |
| Makes the true Zenith Diſtance | 30 | 29 |
| But if by Miſtake | 59 | 15 |
| Be ſubtracted from | 90 | 00 |
| The Zenith Diſtance will be | 30 | 45 |
| And the Sun's Semidiameter being added, | 00 | 16 |
| Makes | 31 | 01 |

Which is 32 Min. greater than the true Zenith-Diſtance, found above, and conſequently produces the Error before-mentioned.

As the Accuracy of the Obſervation will, in a great Meaſure, depend on the two Horizon Glaſſes G and H, being truly adjuſted to that fixed on the Index, when the Inſtrument is held in a vertical Poſition, it will be requiſite that the Artiſt be very careful in performing it, and particularly obſerve, that, during the Operation, the Index continue at the beginning of Degrees, according to the Directions given in *Page* 4 and 5. And as the trouble of doing this is but trifling, the Artiſt would do well to practice it often, becauſe till the Wood is well ſettled, it will be apt to caſt or warp, and, conſequently, cauſe an Error in the Obſervation, which by this Means will be prevented. And, indeed, the Convenience of altering the Poſition of theſe Glaſſes is very great, for thereby the Complaints againſt other Inſtruments, of being Northerly or Southerly, that is, of giving the Latitude too great or too little, may be eaſily prevented.

5. In accurate Obſervations care muſt be taken to keep the Line in which the Object is ſeen, parallel to the Plane of the Inſtrument; which will be beſt performed, if you look thro' the upper Hole, of the Sight Vane L, by taking the Obſervation near the Middle of the unquickſilvered Part of the Glaſs; but if the under Hole be uſed, the Image of the Object ſhould nearly coincide with the Edge of the Quickſilver; then ſwing your Body to and fro, and move the Index till the reflex Image juſt bruſh the Horizon in the loweſt part of its ſwing.

Theſe Particulars carefully attended to, will greatly contribute to the Accuracy of the Obſervation, and render the Uſe of this admirable Inſtrument familiar and eaſy.

10. 8. 10.

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